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STUDY TO DETERMINE EXTRAVEHICULAR MOBILITY UNIT (EMU) ADVANCED TECHNOLOGY REQUIREMENTS

VOL. I - EXECUTIVE SUMMARY

MAY 7, 1976

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CONTRACT NAS2-8957

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G. L. Wengrow
Study Manager

FOREWORD

The "Study to Determine Extravehicular Mobility Unit (EMU) Advanced Technology Requirements" was conducted for the Ames Research Center by Space Division of Rockwell International Corporation under contract NAS2-8957. The contract Technical Monitor for Ames was P. D. Quattrone, Chief of the Environmental Control Research Branch. P. D. Quattrone was assisted by H. C. Vykukal and B. W. Webbon of the same branch. Cooperation and assistance were also given by personnel at Goddard Space Flight Center, Langley Research Center, and Marshall Space Flight Center.

The final report consists of two volumes, as follows:

Volume I	Executive Summary
Volume II	Technical Analysis

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ILLUSTRATIONS

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SECTION I. STUDY SCOPE AND APPROACH

1.1 STUDY OBJECTIVES

This study was planned so as to derive requirements for extravehicular mobility units that are responsive to the needs of typical Shuttle payloads. This study is an outgrowth of a previous EVA Study [1] that demonstrated cost benefits associated with adopting EVA as a planned mode for a wide range of payload operations. Of particular importance in the study are requirements which might require technology advances. The stated objectives of the study are:

Identify Extravehicular Mobility Unit Technology Advances Responsive to Payload EVA Applications

Enlist Active Participation of Payload Community in Substantiating EVA Applications for Payload Operations

1.2 STUDY APPROACH

The EMU study was divided into two phases. Phase I was planned to allow for review of previous study data and to develop and test approaches for the Phase II effort. The Phase I review provided an opportunity for additional NASA direction.

Phase II of the study required investigation of EVA interfaces and reviews of payload characteristics with the payload community in several NASA centers. These reviews included efforts to validate concepts of EVA-oriented designs developed in the previous study. Using these data, design and operations analyses were performed to derive EMU requirements. The following diagram, Figure 1-1 illustrates the study approach.

1.3 BACKGROUND

Pressure suits and life support systems in the past have primarily been developed around physiological and human engineering requirements. In addition, they were primarily planned for the specific activity of Apollo lunar exploration and adapted to Skylab for ATM film retrieval. However, with the Shuttle, and its variety of payloads, a broad range of tasks and activities are potential EMU design drivers. Table 1-1 compares the relative magnitude of potential Shuttle program to previous manned space flight programs.

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[1] "Study to Evaluate the Effect of EVA on Payload Systems", NAS2-8429. Final Report, Rockwell International SD 75-SA-0028, November 1975.

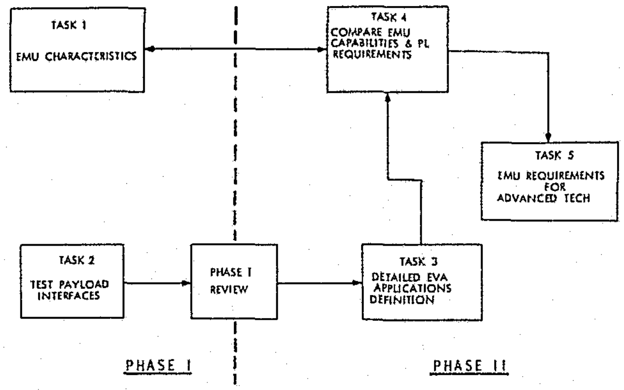

Figure 1-1. Study Approach

	MERCURY	GEMINI	APOLLO	SKYLAB	ASTP	SHUTTLE
TOTAL MAN-HOURS	54	1940	7506	12,351	652	557,000
EVA MAN-HOURS	--	12	168	82	--	15,560 *
NUMBER FLIGHTS	6	10	11	3	1	572
CREW SIZE	1	2	3	3	3	~4

*PREDICTED FROM EVA STUDY FOR PLANNED P/L OPERATIONS: (APOLLO EVA MH RATIO - 12,467) (SKYLAB EVA MH RATIO - 3,698)

SHUTTLE PROVIDED: 13,728 FOR PAYLOADS
6,864 SHUTTLE RESERVED TOTAL - 20,592

Table 1-1. U.S. Manned Spaceflight Data

Over 15 thousand man-hours of routine payload-related EVA can be predicted from the "EVA" study. This represents a higher percentage of total EVA man-hours than either Apollo or Skylab, but correlates approximately with Shuttle-provided EVA capability for payloads (over 13,700 EVA man-hours). Contingency EVA man-hours could increase this total by a factor of two or three.

The significance of these data are that they emphasize the overall importance of EVA for Shuttle payload operations and, therefore, the importance of ensuring an efficient and effective EVA capability.

1.4 PREVIOUS STUDY RESULTS

The "EVA" study analyzed thirteen representative payloads. Baseline (automated) modes of operation were evaluated and compared to EVA modes. In all cases, utilization of EVA resulted in design simplificantion and lower costs. Net savings attributed to EVA for DDT&E and first unit costs averaged $2.5 million for each automated spacecraft program and $8.9 million for each sortie payload program.

Cost savings for the 13 representative payload programs were extrapolated to the total NASA "572 Flight" traffic model whereby costs were estimated for 74 programs with 249 flight units. Net EVA savings were extrapolated to over $551M for NASA and U.S. civil payloads for routine operations. Adding DoD and ESA payloads increased the net estimated savings to $776M.

EVA savings for contingency problems of payloads were based on transport and equipment costs due to payload failures. Historical anomaly and failure data were extrapolated to the Shuttle payload model. To the extent that EVA can be applied successfully in preventing or resolving failures, reflight or jettison losses, a savings of up to $1.9 billion could be realized.

1.5 SUMMARY OF STUDY APPROACH

Initial examination of the interface of EVA crewman-to-payloads resulted in requirements being placed into three groups:

1. Crew protection (from payload-related hazards)

2. Crew performance (related to payload tasks)

3. Payload protection (from EVA-payload tasks)

Twenty requirements types were identified in these three groups. Requirements for the EMU were then derived in these categories from four primary sources: payload design characteristics, payload missions and operations, EVA tasks, and EMU operations characteristics. A matrix of these requirements categories and derivation sources is shown in Table 1-2.

Table 1-2. Matrix of Requirements Types/Derivations

REQUIREMENT CATEGORY	DERIVATION SOURCE			
	PAYLOAD DESIGN	PAYLOAD MISSION	EVA TASK	EMU OPERATIONS
I. CREW PROTECTION				
1. Flammability	X			
2. Thermal	X	X	X	
3. Durability	X	X	X	
4. Dielectric properties	X			
5. Radiation resistance	X	X	X	
6. Penetration, abrasion resistance	X			
7. Fluid resistance	X			
8. Impact resistance	X		X	
9. Bio-contamination	X			
II. CREW PERFORMANCE				
1. Reaction time	X			
2. Force interfaces	X		X	
3. Mobility	X		X	
4. Visibility/orientation	X			
5. Communication	X			
6. Operating time	X			
7. Reliability/maintainability			X	
III. PAYLOAD PROTECTION				
1. Contamination	X			X
2. EMI/EMC				X
3. Dielectric properties	X		X	X
4. Surface damage				X

SECTION II. TECHNICAL ANALYSIS SUMMARY

The technical analyses were directed toward three primary results: (1) define characteristics of baseline (current) EMU's and determine any deficiencies in performing payload-related EVA, (2) analyze payload characteristics and manual (EVA) design concepts of payload operations to assess EMU design and performance characteristics, and (3) establish EMU design and performance requirements where baseline EMU's are deficient in respect to payload operations. To perform these analyses, both previous and on-going EMU designs were examined. Five specific payloads were analyzed specifically for the study, and a variety of other payload data were reviewed to identify unique characteristics as well as to determine frequency of occurrence. Previous study EVA operations concepts were evaluated as they would apply to overall Shuttle missions. This provided statistics on number of EVA's per mission, EVA durations, and other operational data.

This section summarizes results of these analyses. EMU requirements derived from the analyses are summarized in the next section.

2.1 CURRENT EMU CHARACTERISTICS

Four specific pressure suit designs or design concepts were selected for evaluation:

1. Apollo/Skylab EMU - A7L-B
2. Advanced Extravehicular Suit (AES)
3. Shuttle EMU - JSC Concept
4. Ames Research Center Concept

2.1.1 A7L-B

The A7L suits, Figure 2-1 were custom sized to individual astronauts. The pressure suit was essentially a rubberized bladder with outer restraint fabric. Joints were constructed of dipped convolutes. Closure was effected with a full torso back zipper. Operating pressure was a nominal 26 x 10^3 newtons/m^2 (3.7 psi). Contamination sources of the A7L suit have been quantified. Particulate matter (dust, lint, metal) ranges from 0.5 to 500 microns. Leakage of the suit includes 7 grams (0.016 pounds) per hour (primarily O_2 and CO_2) and organics (trace gases), 0.004 grams (9.5 x 10^{-6} pounds) per hour. Of greatest concern perhaps is the H_2O coolant vapor of about 0.78 kilograms (1.72 pounds) per hour (variable).

2.1.2 Advanced Extravehicular Suit (AES)

Advanced technology developments conducted in recent years are typified by the AES which stressed high mobility capability at 34 x 10^3 newtons/m^2 (5 psi) operating pressure level. The suit assembly, illustrated in Figure 2-2, never proceeded to an operational configuration, consequently is shown without a thermal-meteoroid outer garment. Overall suit mobility was excellent. The

Figure 2-1. Skylab EMU (A7L)

Figure 2-2. Advanced Extravehicular Suit

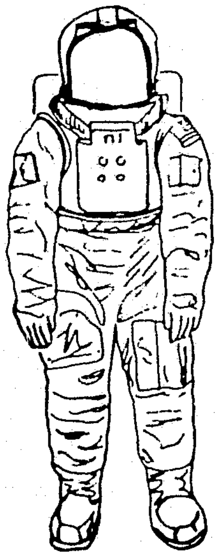

Figure 2-3. Shuttle EMU - JSC Concept

suit was constructed of multi-laminated (soft) fabrics and featured joints of rotating conical sections at the shoulder and torroidal convolute joints at various extremity locations. The waist closure was a horizontal ellipse with a circumferential clamp.

2.1.3 Shuttle EMU - JSC Concept

Recent procurement action was initiated to secure bids on EMU's for the Shuttle program. Cost and technical proposals were requested for suits and life support systems for a concept illustrated in Figure 2-3. The EMU is specified to operate at 28 x 10^3 newtons/m^2 (4 psi) and incorporates a pre-assembled portable life support system. The following data are extracted from the Shuttle EMU Request for Proposal.[1]

The specific design of the pressure garment includes the following features:

a. Hard upper torso

b. Tucked fabric joints

c. Sealed bearings at mobility joints (shoulder, arm, and waist elements)

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[1]Request for Proposal No. 9-BC7-4-6-1P, Space Shuttle Extravehicular Mobility unit, dated December 12, 1975, JSC.

d. Hard ring torso entry closure with sealed bearing

e. Removable bubble-shaped helmet

f. Removable Extra Vehicular Visor Assembly (EVVA) with replaceable visors

g. Non-custom standard sizing with length adjustment provisions at the arms, legs, and torso

h. Non-custom standard sizing range for boots and gloves

2.1.4 Ames Space Suit Assembly

Figure 2-4 shows the Ames space suit assembly (SSA) which is currently being develcped as an advanced technology design.[1] A detailed review of advanced suit configurations, component developments, and mobility provided the basis for selection of the configuration shown. The SSA can be considered as a hybrid suit in that it incorporates both hard and soft suit components.

The torso configuration employs hard structure above and below the suit entry closure. The torso closure, currently under fabrication is geometrically a dual plane closure. This torso configuration provides maximum area on the back of the suit for mounting the life support system (LSS) components and allows for easier entry into the suit as compared to the rotary bearing waist closure used in a previous Ames suit. Hemispherical helmet and connector assembly will be utilized. Waist mobility will be provided by a single axis, "elliptical", dual opposed rolling convolute joint. Maximum mobility, minimum leakage, long operational life, and ease of fabrication at low cost are of primary concern in this development.

A major factor in the Ames SSA is the use of 55×10^3 newtons/m^2 (8 psia) internal operating pressure, in comparison to the 4.0 psia Shuttle EMU. Use of the higher pressure level permits EVA without oxygen prebreathing period.

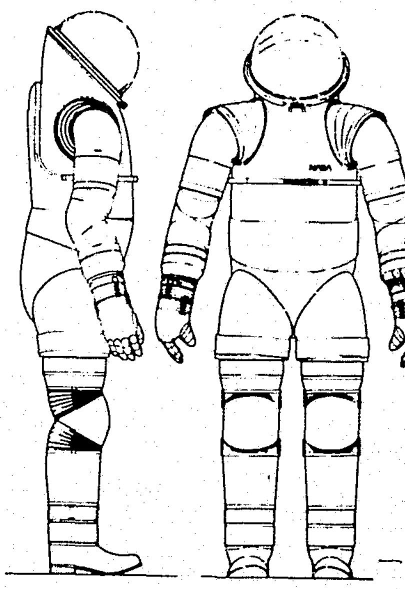


Figure 2-4. Ames Space Suit Assembly

[1] "High Pressure Space Suit Assembly", NASA Technical Memorandum TMX-62515, Hubert C. Vykukal and Bruce W. Webbon, December 1975.

2.2 PAYLOAD EVALUATION

In contrast to previous EMU requirements developements, this study was performed to identify requirements resulting from the application of EVA to Shuttle payloads. Five representative payloads selected for the study, and their responsible center are:

Payload	Responsible Center
Atmospheric, Magnetospheric, and Plasmas in Space (AMPS)	MSFC/GSFC
Space Telescope (ST)	MSFC
LANDSAT-D (EOS)	GSFC
Astronomy Spacelab Payload (ASP)	GSFC
Advanced Technology Laboratory (ATL)	LaRC

The payloads listed were selected to meet the following criteria:

1. At least one payload from the payload centers of MSFC, GSFC, and LaRC.
2. Payload data from the EVA contract or from currently contracted in-house studies.
3. Payloads reflecting a wide range of candidate EVA tasks.

Specific reviews were conducted at NASA centers, within the following functional offices:

Goddard Space Flight Center

Shuttle Payloads Office - Multi-mission Modular Spacecraft (MSS)
- Astronomy Spacelab Payloads (ASP)

Langley Research Center

Shuttle Experiments Office - Advanced Technology Laboratory (ATL)

Marshall Space Flight Center

Program Development - Preliminary Design
Science and Engineering - Systems Analysis and Integration

These reviews were planned to present EVA concepts, validate payload design data in the study and identify payload-to-EVA interface problems. The results of this review can be summarized as follows:

- *Planned Use of EVA Offers Attractive Design Alternatives in Cost Savings, Simplicity, and Reliability*

- *Payload Designers Require Assurance of Reasonable EVA Performance*

- *EVA-to-Payload Interfaces Are Not Adequately Understood by Payload Designers and Require Further Dissemination*

- *Lack of Definition of Shuttle Provisions (i.e., Multi-Mission Equipment) and User Charge Policies Has Resulted in Uncertainty in Payload Design Trades*

- *Concurrence was generally achieved on validity of design data, and EVA concepts*

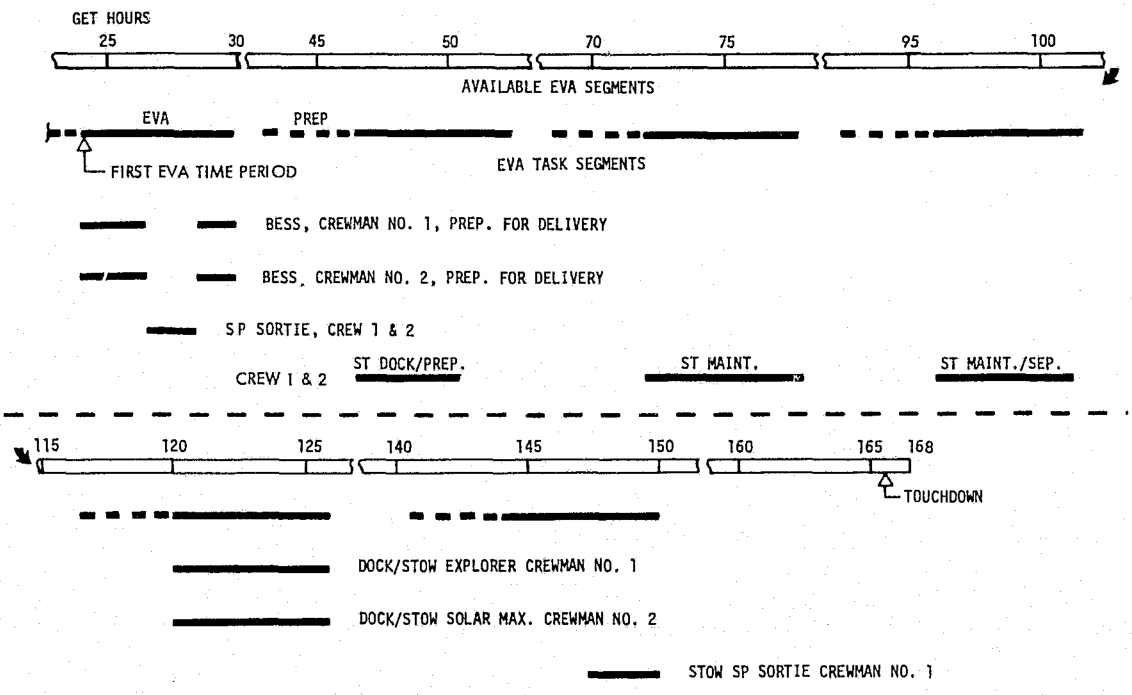
The reviews further provided details on payload design characteristics which influence EMU requirements (e.g., mass properties and surface finishes which determine thermal properties, etc.). Mission characteristics were defined (desired orbit, attitude constraints, etc.), as they affect EMU thermal and radiation protection.

2.3 MISSIONS/OPERATIONS EVALUATION

Timeline data from the EVA study were extrapolated to all 572 payload flights to assist in deriving sizing requirements for life support, EMU life cycles, payload required exposure to the South Atlantic anomaly, and EVA durations requirements. Numerical summaries were made where requirements would be influenced by frequency of occurrence of EVA with respect to mission elapsed time, EVA duration times, and number of EVA's per mission.

Figure 2-5 presents a mission with multiple payloads. Six candidate EVA work periods are shown which are compatible with crew work cycles. Using candidate tasks and task timelines from the "EVA" study, the following mission sequence was developed: (1) two crewmen egress on the first EVA opportunity, and independently prepare the BESS module for separation. During a remote checkout period, they jointly prepare a space processing sortie for operation. Upon completion of this task, final work on the BESS is accomplished through spacecraft separation, (2) during the second EVA opportunity the two crewmen support Space Telescope docking and preparation for maintenance. Maintenance tasks are completed on two subsequent EVA's followed by separation tasks, (3) the fifth EVA opportunity could be employed in performing EVA tasks associated with docking and stowing two satellites in preparation for entry, (4) the sixth EVA period activity then consists of entry preparations on the sortie payload.

Table 2-1 summarizes the results of the mission operations evaluation. It results from summing EVA tasks on multiple payload missions. The traffic model data called for various combinations of spacecraft delivery, retrieval, on-orbit maintenance or sortie mode. In general, deliveries were accomplished in the first or second period, on-orbit maintenance in the second (and subsequent if required) followed by retrievals. Sortie payloads were normally set-up in the first period and stowed in the sixth. Of interest in the table are that most EVA's (about 65 percent) are one man, that 50 percent of the EVA's occur in the first opportunity. and that 63 percent of the missions have two EVA's (89 percent have 2 or less).



BESS - BIOMEDICAL EXPERIMENTS
ST = SPACE TELESCOPE
SP - SPACE PROCESSING

Figure 2-5. Multiple Payload Mission Timeline

Table 2-1. EVA Mission Summary Data

	MISSION EVA TIME PERIODS						
	1	2	3	4	5	6	TOTALS
EVA-HOURS	1235	267	170	70	61	580	2383
NO. OF EVA's 1 MAN 2 MEN 3 MEN	 249 132 --	 57 32 —1	 28 22 --	 6 11 --	 8 8 --	 147 66 --	 495 271 1
AVERAGE HOURS PER EVA	3.24	2.96	3.4	4.11	3.81	2.72	3.1
% OF EVA's -TOTAL EVA's "6"	50	12	6	1	2	30	

	NO. EVA'S PER MISSION							
	0	1	2	3	4	5	6	TOTALS
TOTAL MISSIONS	36	70	264	34	6	5	3	418
TOTAL EVA's	0	70	528	102	24	25	18	767
% OF MISSIONS	9	17	63	8	1	1	1	
NOTE: NASA, NON-NASA & NON-DoD PAYLOADS ONLY	91% OF ALL PAYLOADS USE EVA							

Each of the requirements areas listed in Table 1-2 were analyzed individually. Final conclusions and recommendations from them are presented in Section III.

SECTION III. CONCLUSIONS AND RECOMMENDATIONS AND EVALUATION OF REQUIREMENTS AREAS

Throughout the study, effort was concentrated on (1) deriving EMU requirements on the basis of payload-to-EVA interfaces, (2) comparing requirements identified with previous or on-going EMU capabilities, emphasizing those with potential advanced technology development, and (3) making recommendations which are quantitative if possible, or qualitative, which reflect identified deficiencies of current EMU's to meet payload requirements.

3.1 SUMMARY OF RECOMMENDATIONS

In addition to the detailed results appropriate to each requirement area, a recommendation was considered as to appropriate disposition. Seven categories of disposition were defined as follows.

1. Standard design and development--for those requirements where data developed in the study should be sufficient for a designer, using standard practices, to accomplish a design solution.

2. Standard human engineering and physiological requirements--for those cases involving further interpretation of requirements to ensure that design solutions are appropriate to the crewman.

3. Lab testing required--some requirements could not quantified with study resources, some requirements could only be quantified as to the interface--not as to processess or materials to meet a requirement. For these requirements, laboratory testing programs are recommended.

4. Further study recommended--the probable disposition in some cases is for more in-depth study to be conducted, either in conjunction with or preceeding additional test/development activities, thus ensuring proper direction to the more costly DDT&E activities.

5. Technology development required--this group identifies those cases where state-of-the-art advancement is warranted to meet requirements areas.

6. Performance simulations recommended--for those requirement areas, primarily those which were subjective or based on estimates highly dependent on assumptions, where neutral buoyancy or Keplerian trajectory simulations are necessary to obtain precise quantitative data.

7. STS documentation/specification compatiblity--In a few cases, EMU requirements may be driven by STS documentation. It is not now clear, in many cases, whether the EMU should meet STS subsystem specifications or whether it should be treated as a payload in meeting STS requirements, nor even what these are. Possible areas of omission in this respect are identified.

Ten of the 20 requirements areas should be able to be resolved by application only of standard design practices, or with supplementary testing, standard life sciences inputs, or STS document requirements. The radiation requirement area requires a developmental study to consider physiological dose rates from all sources and which reflect crew flight schedules. In addition, lab testing and technology status of EMU protective materials are required. Four requirements need simulations in neutral buoyancy or zero-g in conjunction with other design or test activities to develop quantitative requirements data. In at least one case, bio-contamination, laboratory testing may define or rule out requirements for the EMU.

The requirements relative to reaction time appear to require (1) laboratory testing of 8-psi suits for mobility and performance characteristics, (2) a cost effectiveness study, and (3) a review for compatibility with the STS. Mobility and contamination areas require lab test data and continuing technology development. Finally, the reliability requirements need an in-depth reliability analysis and application of reliability design principles.

Table 3-1 summarizes these study recommendations.

Table 3-1. Requirement Type Recommendations Summary

Requirement Area	Standard Design Development	Standard Human Eng'r & Physiological Reqm'ts.	Lab Testing Recommended	Further Study Recommended	Technology Development Req'd.	Performance Simulations Recommended	STS Document/Compatibility
Crew Protection							
Flammability	X						
Thermal	X	X	X				
Durability	X		X			X	
Dielectric Prop.	X		X				X
Radiation Resistance		X		X	X		
Penetration/Abrasion	X		X	X			X
Fluid Resistance	X		X				
Impact Resistance	X		X			X	
Bio Contamination			X				
Crew Performance							
Reaction Time			X	X	X		X
Force Interfaces	X		X			X	
Mobility			X		X		
Visibility/Orientation	X	X				X	
Communication	X						X
Operating Time	X			X			
Reliability/Maintenance	X			X			
Payload Protection							
Contamination			X		X		
EMI/EMC	X			X			X
Dielectric Properties	X		X				
Surface Damage			X			X	

3.2 REQUIREMENTS REVIEW

The requirements areas were analyzed on the basis of a potentially full range of payload characteristics, mission operations, and EVA tasks. That is, planned operations, including on-orbit maintenance, and for response to payload failures (contingencies). The evaluation assumed that the crewman might interface with payloads with various systems operating and could include exposure to potential hazards. For example, the EVA crewman could operate in the vicinity of the orbiter Ku-band rendezvous radar or various payload RF sources. The crewman could be performing disconnect operations or servicing for various payload fluid systems. The EVA astronaut may be performing trouble-shooting or repair of electrical equipment requiring power-on situations (as was accomplished on Skylab). Such interfaces are defined as hazardous and are considered, as in ground operations, to be normal interfaces recognizing the higher risk. Not considered in the study are payload failure modes or accidents such as premature detonation of pyrotechnics, motor firings, high pressure system explosions, failed mechanical devices or similar modes.

3.2.1 Flammability

The review of payload characteristics and flammability criteria indicate that the EMU will not be susceptible to external sources of ignition. In order to maintain flame propagation there must be a flame supporting oxidizer and a surrounding pressure. Therefore, should the EMU be engulfed in an oxidizer, the lack of a surrounding pressure at the Shuttle orbiter altitude will not support combustion. The critical area of concern is within the EMU itself. Any EMU electrical system, must be designed and built such as not to become the ignition source internally to the EMU or the portable life support system. Since this is not a payload-derived requirement, no further analysis was conducted. Standard flammability design practices should meet any requirements.

3.2.2 Thermal

Various EVA tasks were evaluated for potential thermal interfacing with the baseline payloads. The maximum values for the majority of tasks range from -128°K (-230°F) on the low side, to 483°K (410°F) on the high side. By taking the mean and standard deviation for the task-temperatures, it was concluded that -144°K (-200°F) to 394°K (250°F) are the appropriate design to range for natural environment. Functional temperatures will fall within a smaller range, except for fin temperatures of RTG's. For this case, 522°K (480°F) and for natural extremes, it is recommended that separate protection be applied for the few instances it is required. Follow-on recommendations indicate application of standard design and physiological principles as well as laboratory testing of thermal protective characteristics of candidate glove materials and thicknesses at these interface temperatures.

3.2.3 Durability

Evaluation of EVA tasks indicate that flexing of the EMU occurs primarily at the waist and shoulders and in the hand, wrist, and arm areas. Waist mobility is highly desirable to allow the astronaut to see around blocked areas during EVA. The waist must be substantially designed to withstand continual flexing in this.

Based on estimates of EVA tasks extrapolated to the traffic model payloads, flexing cycles range from 16 to over 200 thousand cycles. Although current life cycle capability could not be determined, Apollo/Skylab "soft suits" tended to indicate early wearout characteristics. It is recommended that task simulations be conducted to establish empirical data, followed up with lab testing of the effects on various materials.

3.2.4 Dielectric Properties

EMU materials and construction must be non-conductive so as not to be painful nor injurious to EVA crewmen, damaging to payload components, and so as to prevent static potential during payload operations. Although Skylab EVA's included unscheduled repairs during power-on situations, no data were available regarding possible EMU conductivity. It should be clear, however, that the scope of orbiter payloads may increase the potential hazard to crew and to payload components. Laboratory testing of materials and identification of EMU properties in STS documentation are recommended.

3.2.5 Radiation Resistance

During EVA exposure to RTG's, the crewman would receive about 1/4 to 1/2 the allowable daily dose. Since only about 20 payload deliveries in the payload model for 1980 through 1991 would be likely to utilize the RTG, there does not appear to be a basic design requirement. However, since contingency operations may be required, special purpose protective over gloves could be a consideration.

The daily dose from Van Allen sources during one six-hour EVA period in the worst orbits could equal 30 rads, about 1/3 the 30-day allowable radiation assuming 0.3 gm/cm^2 shielding equivalent from the EMU. Although study data indicate that EVA's typically would average about 3.1 hours, conservative design should probably anticipate 6-hour EVA's. Also, statistical estimates indicate an average of 1.8 EVA's per mission. Technology research is recommended to determine EMU shielding capabilities, and to perform further analyses of the required protection so as not to exceed allowable dose limits if routine EVA is to be allowed.

Indications are that the equivalent of 0.4 to 0.45 gm/cm^2 would be desirable for routinely available EVA. Technology investigation of suitable materials with satisfactory mobility characteristics is recommended. A study of Shuttle astronaut career activities may also be required, as well as physiological inputs as to their other radiation exposures from space and atmospheric flights.

3.2.6 Penetration, Abrasion

With hundreds of spacecraft and sortie experiments being planned or developed, it appears reasonable to ensure EMU protection against various spacecraft design criteria. Manned and unmanned spacecraft standards suggest that EMU designs should tolerate at least a 0.038 cm (0.015 inch) radius as being the sharpest identified. While random burrs or screw heads are more difficult to define, laboratory investigation of material resistance is indicated. Although it would appear that protecting the EMU would be cheaper than requiring extensive radiussing of all payload edges, a cost trade may be warranted.

3.2.7 Fluid Resistance

Crew activities in support of the various payloads will require development and testing of suit materials under exposure to diverse elements such as cryogenics, hydrazine, and other propellants to establish the selection of required suit materials.

3.2.8 Impact Resistance

Estimates are that crew translation rates could be in the order of 1 to 1.5 meters per second (~4 to 4.4 feet per second). Considering the mass of the suited crewman, forces in the order of 2224 N (500 lb) could be expected. If an exposed corner were encountered, with a radius of about 0.64 cm (0.25 in.), the pressure could reach 5500 N/cm^2 (8000 psi).

It is recommended that lab testing be conducted to determine the extent of damage especially to areas of the EMU such as the helmet and backpack which are hard surfaces and where the crewman's viewing may be impaired. Underwater simulations may be important to develop techniques for pushing off and for evaluating capability of the crewman to push off. It should also be noted that sharper radii may be encountered--see paragraph 3.2.6 above.

3.2.9 Bio-Contamination

Although various payloads carry organic specimens, the actual amount of biological contamination is difficult to predict due to the unknown types and quantity that might adhere to the EMU. Further research and laboratory tests appear to be in order to determine viability of various organisms in a vacuum and any necessary control techniques.

3.2.10 Crew Reaction Time

Result of previous studies indicate that operation at 8 psia will improve operations and that substantial cost savings could be attributed to quick reaction; e.g., increased experiment time in an EVA mode. The 8 psi suit offers the greatest potential for improved reaction time by elimination of prebreathing. Current technology developments for a 55 x 10^3 N/m^2 (8 psi) system are projected to equal or exceed mobility capability of previous technology 34 x 10^3 N/m^2 (5 psi) systems. Other considerations include technology risk and development costs compared to the baseline Shuttle EMU. Comparative cost analyses are required for 8 psi qualification versus cost benefits from reduced EVA response time. Continuing technology development is recommended as well as lab testing of characteristics of the higher pressure suit.

3.2.11 External Interface

Based on evaluation of EVA tasks, the crewman will frequently be required to react forces from various segments of the EMU. Primary interfaces for this force reaction will be gloves, front of waist, top and bottom of boots, front and back of lower leg, front and back of knees, and shoulders. Value of the applied force will range from about 110 to 200 Newtons (25 to 45 pounds). Simulations to validate where forces are reacted and lab tests of EMU materials (especially thermal/meteoroid garments) is recommended.

3.2.12 Mobility

The importance of EMU mobility in terms of range of motion have been recognized in recent EMU developments. Both the current Shuttle EMU procurement and the Ames suit development activities recognize the importance of these factors in performing a variety of tasks and reducing crewman fatigue. No delta requirement was found in this study. Continued technology and lab testing are recommended to maximize mobility with minimum torque.

3.2.13 Visibility/Orientation

Optical characteristics of the helmet have been thoroughly analyzed and do not present a problem. However, two payload interface problems were identified. It was concluded that the crewman has little or no visibility of the backpack assembly, and must rely on a sense of its bulk. Supporting research should be employed to determine the scope of the problem and potential design solutions such as "cat whiskers" or relocation of life support components to more visible areas. It is recommended that simulations be conducted in a backpack mode, and, if orientation problems are encountered, that life support component packaging design and location (e.g., to front or side areas) be investigated. In addition, reflectance characteristics of 85 to 95 percent of various payload surfaces indicates potential visor design requirements.

3.2.14 Communications

Voice communications will be mandatory during EVA periods. During certain periods such as spacecraft rendezvous and docking and for various payload operations, some communications interference may be encountered, unless special precautions are taken. These precautions include the insertion of appropriate true-trap filters to absorb undesirable RF energy which may be generated from such sources as the rendezvous radar or scientific RF generating equipment. In addition, special shielding may also be required for the EMU amplifier circuits for suppression of other spurious signals. It could not be confirmed that these requirements are currently imposed on Extravehicular Communications System (EVCS) design.

3.2.15 Operations Time

A statistical summary of mission EVA durations was compiled, based on the "EVA" study. The data show that all EVA's can be performed in less than 6 hours. Durations range from about 1.8 hours to just under 6 hours. The majority of EVA's, 62 percent, require less than 2.7 hours. A more uncertain area is that of contingency EVA; however, Skylab data show that of three major and several minor contingency repairs performed EVA, none exceeded 4 hours. However, further study, especially in advanced solar power station support concepts or on the basis of Shuttle/payload failure modes and effects may indicate the requirement to increase suit operating time beyond 6 to 7 hours per day. It is recommended that EMU requirements consider capbaility to extend or add to an EVA to accomplish up to 8 hours by use of kits, recharge, or perhaps modular exchange of life support units. Life support units sized at 4 hours could perform most EVA's, but could then extend EVA's easily with beneficial effects on backpack size.

3.2.16 Reliability/Maintainability

The EMU system must possess the reliability to provide the crewman with the capability to retract/safety all the applicable booms, antennas, latches, locks, and cover all optics and sensors that were designed for EVA. The EMU system must also ensure availability of the crewman to override any automated mechanism or operation which incorporates an EVA performance requirement. Current design goals have only identified crew safety as a reliability requirement. Reliability of crew response for payload manual designs should also be added as a design goal. A reliability analysis of EVA response is recommended. The reliability of the EVA system must in all cases be equal to the reliability of the automated system it is designed to replace.

3.2.17 Contamination

Primary concerns are particulates and water vapor. Since particulate adherence to optics elements in zero-g is not likely, reasonable care should be adequate. A possible design objective for materials could be to ensure that particulate diameters be <5.0 microns. Condensate control has been frequently studied. Solutions involving directional control appears to be adequate at present (i.e., rearward venting only). However, advanced development is recommended which could include positive containment with remote venting or perhaps closed systems.

3.2.18 EMI/EMC

Electrical systems of the EMU must comply with Specification SL-E-0001 (Electromagnetic Compatibility Requirements for the Systems for the Space Shuttle Program) during all phases of the Shuttle mission as specified in the EMU RFP and Specification SL-E-002 (Electromagnetic Interface Characteristics Requirements for Equipment for the Space Shuttle Program). Since EMI/EMC requirements for payloads have not been specified, further review and monitoring of STS documentation are required to ensure EMU compatibility with payloads.

3.2.19 Dielectric Properties

Considerations and recommendations are the same as for paragraph 3.2.4.

3.2.20 Surface Damage

In general, payload structured areas are not easily subject to damage by the EMU suited crewman. However, various areas of thermal coatings and fragile elements such as solar cells can be easily damaged. Since all factors of EVA interface cannot be specified, only general design requirements can be established. These include: improved mobility to maneuver about the payload, clear viewing of translation path, reduction of backpack volume (since this region cannot be seen by the crewman), padding of hard elements of the EMU, and minimal abrasive characteristics of the EMU gloves. Neutral buoyancy or other simulations of crew body handling plus lab testing of damage characteristics are recommended.